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Beneficial Effects of an Intercepting Trench on Degraded Ground Water in the Vicinity of a Refuse Landfill

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BENEFICIAL EFFECTS OF AN INTERCEPTING TRENCH ON DEGRADED GROUND WATER IN THE VICINITY OF A REFUSE LANDFILL

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser Date

Head, Civil Engineering Department Date

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INTRODUCTION

Sanitary landfills were established as an improved means for the disposal of refuse. This method of disposal considered the concepts of land reclamation, natural beautification, and public health. Therefore, this systematic approach to refuse disposal, if properly conducted, could eliminate the objectionable nuisances (odors, smoke, litter, and public health hazards from rats and flies) associated with the method of open dump disposal. However, great concern has been expressed about ground water contamination by infiltration and percolation, refuse decomposition, gas production and movement, leaching, and ground water travel within and from these sites.

In 1961, a nationwide symposium was held at the Robert A. Taft Sanitary Engineering Center to outline present knowledge of ground water contamination and to guide future studies within this area. After devoting considerable time and attention to this subject, the symposium concluded that immediate information was needed concerning geologic and climatic characteristics of disposal sites where possible leaching of refuse was occurring (1).

Further concern was signified by Sheaffer (2) in 1963 at the National Conference on Solid Waste Research in Chicago, Illinois. Sheaffer stated that there was surprisingly and unfortunately insufficient concern for the pollution of one of our most valuable resources - ground water. A definite need exists for more research in the areas of the nature and mobility of chemical and biological contaminants leaching from a sanitary landfill. This includes studies of existing disposal sites located in environments that are potentially unfavorable (2). At this same conference, Black (3), while discussing research needs, expressed an interest in developing methods for sealing pits so that abandoned quarries and other excavations could be used without danger of polluting the ground water.

Finally, in 1965, the concern for problems associated with refuse disposal was felt so strongly by Congress that they passed the Solid Waste Disposal Act which created the Office of Solid Wastes within the Public Health Service. This act provided for (4):

> . . . the initiation of a national research and development program relating to solid waste disposal, including studies directed toward conserving natural resources and recovering and utilizing potential resources found in solid wastes, and the provision of technical and financial assistance to State and local governments, and interstate agencies in planning, developing, and conducting solid waste disposal projects.

The concern for ground water contamination resulting from the sanitary landfill method of disposal, the realization that adequate data were lacking, and the availability of a refuse landfill that could be used for obtaining more pertinent data, resulted in several research projects at this university. These included: a study of the effects of the refuse landfill on the quality of the underlying ground water (5); a study of the areal extent of the contamination and the variance due to seasonal changes (6); and a study of the effects of the refuse landfill on the subsequential uses of the related ground water (7). These investigations reported that a small pond located within the vicinity of the landfill could possibly improve the quality of the contaminated ground water. Because of these reports and the lack of knowledge of the beneficial effects of open bodies of water on ground water quality, a research proposal to investigate these effects was initiated. This study presented herein pertains to the influence of a man-made trench that intercepts the ground water flow after it passes through a landfill site.

LITERATURE REVIEW

Refuse Disposal on Land

At the nationwide symposium held at the Robert A. Taft Sanitary Engineering Center in 1961, it was reported that 1400 communities were utilizing the sanitary landfill method of disposal while thousands of other communities were disposing of their refuse by the insanitary method of "open dumping" (1). Those employing the sanitary landfill method of disposal were preventing objectionable nuisances such as odors, smoke, blowing debris, and rats and flies.

The sanitary landfill method of disposal is designed on the basic idea that refuse will be deposited, compacted, and covered each day in trenches or cells to eliminate nuisances and hazards associated with open dumping. Proper operational and maintenance procedures include (8-13):

1. The disposal of wastes by the landfill method should be planned as an engineering project. Operations and maintenance should be under the direction of a sanitary engineer.

2. The face of the working fill should be kept as narrow as is consistent with proper operation of trucks and equipment in order that the area of waste material exposed during the operating day be minimal.

3. The exposed surface should be covered with earth as promptly as is consistent with proper operation, and at the close of each day's operation both the surface and the face of the fill should be completely covered, the object being to make a closed cell of each day's deposit.

4. The final covering for surface and side slopes should be maintained at a depth of approximately 24 inches.

5. Spraying of the exposed waste material and adjacent surfaces should be used when necessary to allay dust.

6. As a rule, the layer of refuse should not exceed an average depth of about 8 feet after compacting. Where deeper fills are necessary, the filling should be carried on in stages.

7. All collections of surface waters resulting from these landfill operations should be drained, filled, or treated with effective chemicals so as to prevent mosquito production or allay disagreeable odors.

The advantages of a sanitary landfill as compared to other satisfactory methods of land disposal can be summarized as: relatively low operational and maintenance costs, simplicity and flexibility of operation, accommodation of all types of refuse without a need for separation, and reclamation of previously unusable land for economic benefits and improved environmental conditions (9), (10).

However, much confusion has developed over nomenclature in the technical literature because of the general tendency to regard all refuse disposal sites as sanitary landfills. This is in correlation with the city officials' self-esteem to be known to have established a sanitary landfill operation. Those that do not maintain compaction and covering procedures daily are termed "modified sanitary landfills" (10) or "refuse landfills" (3). Black (3) states that the reason for not complying with the sanitary landfill operational procedures is one of expense. It has been estimated that the cost of the "refuse landfill" operation is about one-half the cost of the sanitary landfill operation.

Decomposition Processes and Gas Production

The decomposition processes relative to sanitary and modified sanitary landfill methods of disposal generally occur within the fill area and may proceed within the adjacent ground and ground water areas (11-33). Organic matter present within the disposed refuse at the landfill will be decomposed by bacteria and other microorganisms and utilized as a source of food. This decomposition may occur under either aerobic or anaerobic conditions.

An aerobic process will predominate if sufficient atmospheric oxygen is present. The organisms will utilize the free oxygen while decomposing organic matter, thereby producing carbon dioxide and water; organic nitrogen will be released as ammonia (11-32).

Aerobic Process

$$CH_aO_bN_c + dO_2 \longrightarrow eCO_2 + fH_2O + gNH_3$$

Gas analysis data collected at a landfill in California (12-55) revealed that oxygen concentrations were reduced to below 1.5 percent at a three foot depth. Increases in nitrogen content were noted. From this, it appears that aerobic decomposition of refuse in a landfill probably occurs only in the shallow depths. Nevertheless, it is difficult to measure exactly this depth because of the variation in the type of overlay, degree of compaction of the refuse, composition of the refuse, and climatic conditions.

In the absence of atmospheric oxygen, an anaerobic process will occur producing numerous products. These, when a wide variety of organisms participate in the fermentation, will primarily be methane, carbon dioxide, and secondary by-products such as ammonia.

Anaerobic Process

$$CH_aO_bN_c + dH_2O \longrightarrow eCO_2 + fCH_4 + gNH_3$$

These two processes will eventually break down the decomposable organic refuse to produce the final products (CO_2, CH_4, NH_3) (II-32). Therefore, within the fill area, there are four common gases which are associated with decomposition of refuse. These are carbon dioxide (CO_2), oxygen (O_2), methane (CH_4), and nitrogen (N_2) (II-60). Of these, only CO_2 is appreciably soluble in water. Nevertheless, the concentration of the gases produced is controlled by the composition of the refuse and the existence of oxygen. During the initial phase of refuse decomposition, oxygen will be available. However, unless an adequate mixing of the internal and external atmospheres continues, the atmosphere within the interior of the fill will be depleted, resulting in an anaerobic environment. Once anaerobic conditions are established, the net production of gases in the absence of compensating factors will tend to exclude the outside air, thereby maintaining these conditions (II-47). The resulting gases produced by decomposition will penetrate into the adjacent ground area and will continue to move by diffusion and convection processes. The heavier gases will eventually move downward mixing with the ground atmosphere until they reach the ground water where they may dissolve (II-60).

Methods of Ground Water Degradation

Although many problems were eliminated by instituting the sanitary landfill method of disposal, the effect of the fill area on ground water was not fully apprehended. Because of the numerous substances in a landfill which may dissolve in water, the "universal solvent" (13-32), the potential of ground water contamination was realized. Early studies in California indicated that undesirable substances from sanitary landfills and refuse dumps are possibly introduced to ground water by the principle processes of infiltration and percolation, refuse decomposition, gas production and movement, leaching, and ground water travel through the fill area (11-95). The degree of contamination from all landfills is not consistent due to many interrelated factors. Several factors that need to be evaluated are the amount of annual rainfall, type of soil, climatic conditions, and depth to the ground water table (11-95).

A 1961 report (14-74) of a committee of the American Society of Civil Engineers enumerated data relative to the operation of sanitary landfills. Twenty-seven percent of the sanitary landfills reported by 250 governmental agencies were depositing refuse between zero and five feet above the water table while an additional 20 percent were operating between five and ten feet. However, only six percent of all the sites reported ground water pollution problems. This latter statement may not be representative of the actual ground water pollution that has developed.

The organic and inorganic matter deposited with the refuse may be free to leach out vertically and horizontally with percolating water. The degree of completion to which this extraction proceeds depends upon the accessibility of the soluble matter and rapidity with which the soluble matter is created by decomposition processes (11-68). Leaching may be accelerated when the refuse is in direct contact with the ground water. British data indicated that greater quantities of substances were leached in wet fills than in dry fills (11-72).

In 1952, the State Water Pollution Control Board of California published the results of a comprehensive investigation of leaching from incinerator ash dumps. This study may be relative to refuse areas at which burning is conducted. The following paragraph refers to the conclusions of this investigation (15-15).

> Chlorides and nitrates will be rapidly and completely removed by leaching. Sulfates will be leached at a slightly lower rate. Calcium and magnesium will be leached very slowly, while the rate for sodium and potassium will be the fastest of the cations. It is unlikely that all cations would ever be removed.

The gases given off in the decomposition process may also dissolve in the ground water and alter its quality. Water will combine with carbon dioxide to form carbonic acid. The solution will dissolve iron from tin cans and lime from calcareous materials which are insoluble at a high pH but very easily dissolved in a low pH environment or an acidic solution (11-33). Thus, carbon dioxide dissolved in water may indirectly result in an increase in hardness by dissolving iron from the tin cans and lime from the calcareous materials. Hydrogen sulfide is an example of a gas which dissolves in ground water and imparts an offensive taste and odor to the water.

Movements of Contaminants

Percolating water, as it moves vertically downward to the ground water table, leaches soluble materials from the fill area. Following this, dilution of the contaminated ground water may take place by dispersion into the adjacent ground water during flow (11-87). Statements have been made (11-88) to the extent that this dispersion is not very effective in homogeneous materials consisting of sand and small gravel. Therefore, dispersion by random variations of velocity should not be relied upon as an effective method for diluting ground water pollutants except where large flow irregularities (numerous boulders or lenses of fine sediments) exist in the aquifer.

Furthermore, the permeability of the soil and the gradient of the ground water table will control the velocity of the ground water. For example, if a gradient of 10 feet per mile exists within a stratum of medium sand, the average rate of movement will be a few inches per day (16-18). However, as the permeability of the soil and the slope of the ground water table increases, the velocity of the flow will increase proportionally.

LeGrand, Ground Water Hydrologist of the U.S.G.S. (17), developed a system for evaluating landfill sites for potential contamination of ground water. To utilize this method, five factors: depth to the ground water table, sorption, permeability, ground water table gradient, and distance to point of use of the ground water would have to be measured or estimated. Although the method was only approximate, it nevertheless indicated the possible areal extent of contamination from a point source.

Indication was made by Merz (12-72) that the dissolved mineral matter entering the ground water table will have its greatest travel in the direction of the flow. As the ground water stream transports the pollutants, the concentration will probably be decreased because of dilution.

However, McKee and Wolf (18-19) stated that percolating wastes that enter the ground water table may only be diluted under certain circumstances. On the assumption that the flow in ground water is laminar, they stated that ". . . a small ribbon of polluted water injected into the ground water flow will move in a well-defined stream-line with a minimum of lateral or vertical diffusion and dilution."

Sniegocki (19) indicated in his report that chemical contaminants move farther through an aquifer than bacterial contaminants and are generally more difficult and expensive to remove from water. Kaufman (20) concluded that inorganic contaminants are more indestructible and persistent than organic and biological contaminants; therefore, the present problems involving the contamination of ground water will be of a chemical nature attributed to the ability of the homogeneous soil, free of fissures, to filter out the biological contaminants.

Methods of Enhancing the Ground Water Quality

McCormick (5) and Sawinski (6) concluded from their research studies that the small pond adjacent to the disposal area beneficially affected the contaminated ground water flowing from the fill area by dilution and dispersion. Algae were also considered important in improving the water quality. Thus, there was a possibility of improving the water quality if the contaminated ground water flowed into a man-made open body of water. This improved quality of water could result from dilution and dispersion, aeration, and the presence of algae.

An open body of water which intercepts an aquifer has virtually an infinite permeability compared with any other porous medium and will "attract" flow. As an example, "a cylindrical pit completely penetrating the surface aquifer will collect flow from a width of aquifer equal to twice the pit diameter (11-89)." Therefore, the open body of water will be attracting ground water from the immediate area. Dilution and dispersion will possibly result because of the mixing of the different qualities of ground water.

A uniform quality of water will not be evident within an open body of water attracting different ground water qualities unless certain conditions are prevalent to induce complete mixing. This quality will only result from the establishment of currents within the open body of water. Factors which create natural currents are listed in hydrological references (21-97), (22-28):

1. The movement of water toward an outlet.
2. The inflow of water.
3. Variation in temperature at different depths.
4. Wind.

The concept that vertical currents will be caused by a variation in temperature is based on the fact that water attains its maximum density at 4°C. For example, preceding the formation of ice on the surface of an open body of water, the temperature of the surface water will approach 4°C. Upon attaining this condition, the top layer will sink allowing the warmer water to displace it until an adjustment of the whole body of water results in accordance with maximum density. Vertical circulation will be continuous in shallow lakes less than 20 feet in depth except when the surface is frozen (21-99).

The effectiveness of the wind for mixing an open body of water is very evident. Once the surface water has drifted to one side, gravity will cause a recirculation path that will move the water downward, backward, and upward on the other side. The whole body of water will therefore be in a "sort of rotation" (22-29).

Enhancement of degraded ground water has been reported (11-89) to have occurred at a refuse disposal area at Egham in Surrey County, England. From 1940 to 1960, refuse had been deposited (tipped) into three wet pits. Analysis of water samples obtained from gravel pits and wells within the disposal area revealed that the chloride content had increased from 50 ppm in the native water flowing into the area to

800 ppm in the gravel pits used for disposal of refuse. Additional samples obtained from gravel pits (not utilized for refuse disposal) adjacently downstream from the disposal pits were found to contain 290 ppm of chloride. Other pits located 3500 feet further downstream were reported to contain a concentration of 70 ppm of chloride. The enhancement of the quality of the ground water was attributed to dilution. This effect, occurring during ground water flow, had possibly been induced by the presence of a fairly large area of water-filled pits located along the path of the flow.

Further enhancement of the pond water can be accomplished by the presence of algae. These aquatic plants, one-celled or many-celled, will utilize the surplus amount of CO_2 which is in solution prior to photosynthetic activity (23-62). The photosynthetic action will result in an increase in the amount of stored organic material and a release of O_2 to the environment. This reaction can be represented as (23-62):

$$6CO_2 + 6H_2O \xrightleftharpoons{\text{light energy}} C_6H_{12}O_6 + 6O_2$$

Immediately following the depletion of the CO_2 in solution, $Ca(HCO_3)_2$ will serve as a source of CO_2 causing precipitation of $CaCO_3$ according to the following reaction (23-58):

$$Ca(HCO_3)_2 \longrightarrow \underline{CaCO_3} + H_2O + CO_2$$

This reaction may continue until all the bicarbonate is broken down and calcium hydroxide remains in a strongly alkaline solution (23-63).

These reactions will definitely influence the quality of the pond water and, consequently, the ground water in the following ways (19-302), (23-64):

1. The pH will increase.
2. Total hardness will decrease.
3. Dissolved oxygen will increase.
4. Alkalinity will decrease.

In addition, the dissolved oxygen content in the pond may create an environment that could result in the oxidation of ammonia and sulfides (1), (11-33).

McCormick (5-46) and Sawinski (6-28) reported a reduction of total hardness in the pond which is located within the vicinity of the Brookings landfill area. Algae in the pond were considered as the possible cause of this reduction. They also observed that the hardness of the ground water downstream from the pond was reduced.

Another means of improving degraded conditions which developed during deposition (tipping) of refuse in abandoned gravel pits has been utilized by the boroughs of Kingston-upon-Thames (24). Approximately 750 tons of refuse was disposed of weekly in a pit having a surface area of six acres and an average depth of water of about 12 feet. The ground level was eight feet above the liquid surface level; therefore, a total depth of 20 feet was available for fill. Disposal operations were started on March 1, 1951. As the operation continued, the

the dissolved oxygen content of the water decreased from the saturation value, and the biochemical oxygen demand (BOD) began to rise above its original value of 1.7 ppm. By the end of April 1951, all of the dissolved oxygen had been depleted, and the BOD had increased to 30 ppm. Furthermore, the water developed a dark color, and the smell of hydrogen sulfide was detectable. After the unsuccessful trials of introducing cultures of sulfide oxidizing bacteria and bleaching powder into the water to accelerate the disappearance of sulfides, it was decided to use mechanical aeration. This was considered to be the best and most practical method for combating ground water pollution. The result of aeration at this site was stated as (24):

> The scale of aeration was never quite big enough to achieve aerobic conditions but it would appear that this method is capable of producing satisfactory results, particularly if used in conjunction with the method of tipping dry and pushing old refuse (one year or more) into the water.

Use of aeration was also described for abandoned gravel pits filled with water at Sunbury-on-Thames (24). These pits were filled with general rubble and waste materials other than household refuse. It was reported that the water blackened, and hydrogen sulfide evolved. After several unsuccessful trials using other methods to combat this condition, an aeration plant was employed. At this time, the BOD was 90 ppm, and hydrogen sulfide was 31 ppm. By the end of the 28th day of aeration, hydrogen sulfide was no longer existing, and oxygen was prevalent in solution. The water was again clear and light brown in color.

THE BROOKINGS LANDFILL AREA

Establishment of the Landfill

The City of Brookings had been disposing of their refuse at a location east of the city limits until May 1960. Because the development of new housing was proceeding east, the city was obligated to relocate its refuse disposal area. The new location, one mile east and two miles south of the city, consisted of a quarter section containing several inactive gravel pits. Initial plans were to utilize the depleted gravel pit area for disposing of the refuse. Adjacent areas, now used for farming, were designated for possible use in the future. A small pond was also present along the western edge of the gravel pit area. Refer to Figure 1.

The investigation of geological information (25-37) revealed that the 160 acres obtained by the city consisted of approximately 55 acres of soil classified as Fordville loam, and 105 acres of Renshaw sandy loam, all nearly level. Both classes were characterized by thin sections of alluvium overlying outwashes of sand and gravel.

Because of the generalization of these data, an additional geologic investigation (26) was conducted at the disposal site in July 1965. The following conclusions resulted from this investigation (26).

1. The surface layer consisted of alluvium and till ranging in depth from one to three feet.

2. The underlying layer designated as the outwash, ranged in thickness from 12 to 31 feet. This layer was considered to be the main aquifer and the ground water table was approximately seven feet below the ground surface.
3. The partially saturated outwash layer consisted of thin discontinuous lenses of poorly sorted gravels, sands, silts, and clays. Permeabilities for the various lenses ranged from 2000 feet per day to less than one foot per day, and the computed velocity of flow ranged from three feet per day to less than one foot per day.
4. A second till layer underlying the outwash was composed of clay and silt with some sand and gravel. This deposit was not completely impermeable but could be considered as a hydraulic boundary for the water in the outwash.

Land owners adjacent to the new site expressed concern that the disposal area might possibly contaminate the underlying aquifer which was their source of water. To alleviate this general feeling, the City of Brookings installed eleven well points at five different locations around the periphery of the disposal area. Analyses of the water samples obtained from these wells and measurements of the elevation of the ground water table, were made to establish the degree of degradation of the ground water, the fluctuations of the ground water table, and the direction of the ground water movement (27).

During the fall of 1962, evaluation of the accumulated ground water data indicated that the quality of the water immediately

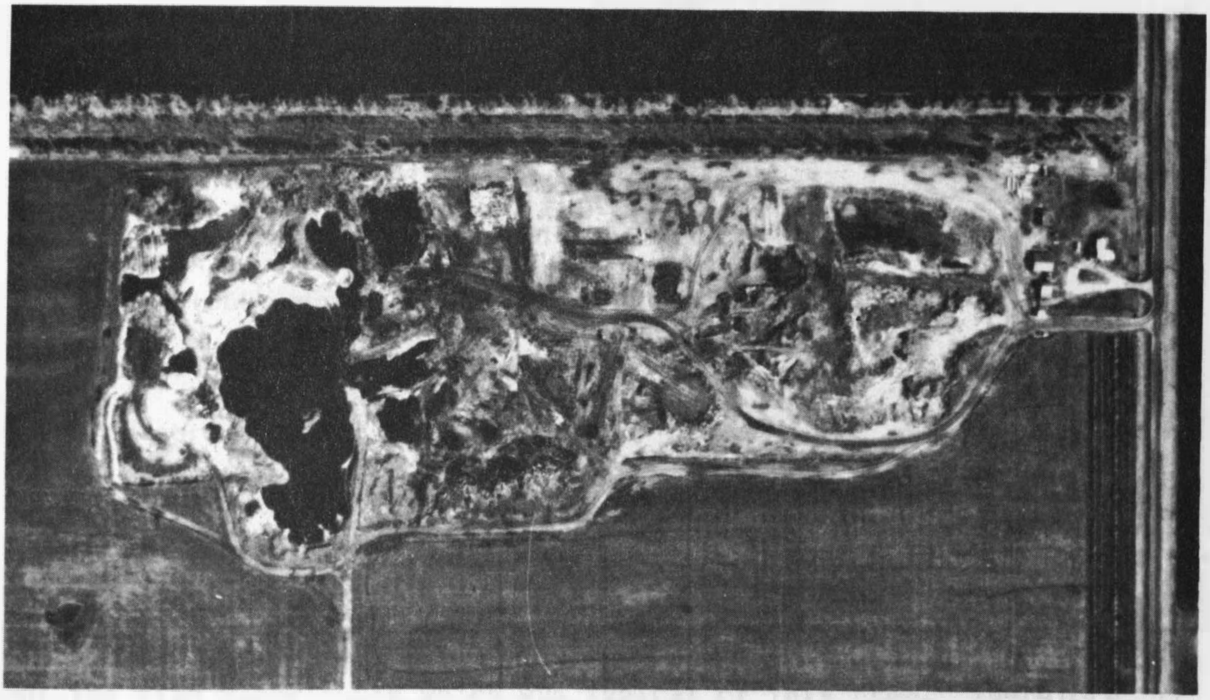

Figure 1. Brookings refuse disposal area, April 1963.

Figure 2. Brookings refuse disposal area, looking toward north, July 1966.

downstream from the fill area had only been slightly degraded. Furthermore, the direction of the ground water movement was established to be approximately southwest.

It is significant to note that the initial operations, started in May of 1960, approximated the procedures for a sanitary landfill. Refuse was segregated for disposal into different areas, compacted and covered periodically, but not burned. During 1962, the city officials recognized that the area designated for disposal would not accommodate the City of Brookings far into the future because of the small depth available for compacting refuse. This depth limitation was the result of the high water table which was typical of this area. Therefore, it was decided to initiate burning of the combustible material to prolong the utilization of this area. This latter operation was technically considered to be only a method of controlled refuse disposal. Even though burning has been a daily characteristic of the landfill operation, the operator has reported that no objections have been received from the farmers in the immediate area.

Construction of the Trench

During March 1966, a private construction company moved to the disposal site to remove gravel. Excavation of gravel to a depth approximately eight feet below the ground surface was initiated just south of the landfill area on March 28, 1966. The extent of this excavation can be observed from Figure 2. With time, excavation proceeded east, west, and then south of the landfill area.

Because of Sawinski's (6) results and conclusions, the city agreed to finance the excavation of a trench (approximately 50 feet wide by 15 feet deep by 700 feet long) along the south side of the disposal area. This location was recommended because it would probably allow interception of the most degraded water flowing from the disposal area. This trench, constructed during November and December of 1966, is evident in Figure 3, and a close-up is shown in Figure 4. The excavation of the trench was started slightly southeast of the old pond and proceeded east along the southern edge of the fill area. Upon completion of this project, data were collected for ten months to determine the beneficial effects of the intercepting trench on the quality of the ground water. During June and July of 1967, the trench was extended westward along the rest of the south side of the landfill area.

EXPERIMENTAL TECHNIQUES

Selection of Sampling Points

To obtain the most significant results, it was necessary to utilize the same sampling points used during Sawinski's investigation. This would enable comparison to be made of all data accumulated before construction of the trench with that accumulated after the completion of the trench. Therefore, during the investigation period, all points destroyed during the excavation of gravel were replaced. As the investigation proceeded, it was further realized that several new sampling points should be installed to provide additional information

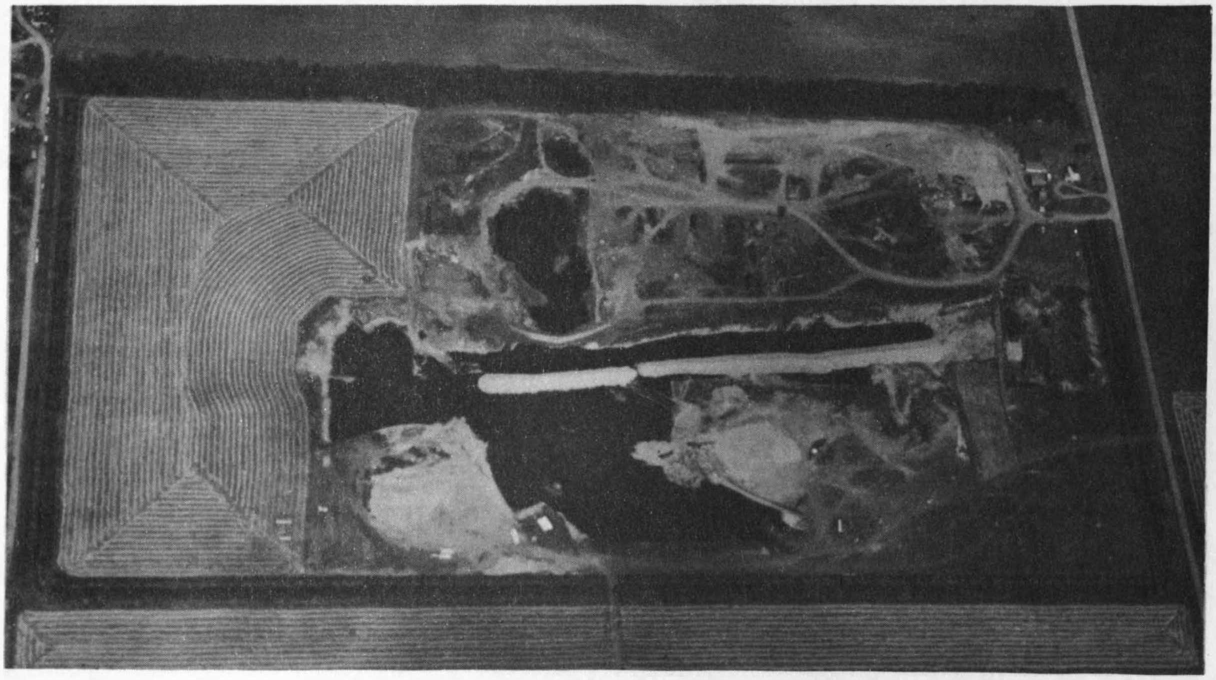

Figure 3. Brookings refuse disposal area showing the extent of the gravel excavation on the intercepting trench, August 1967.

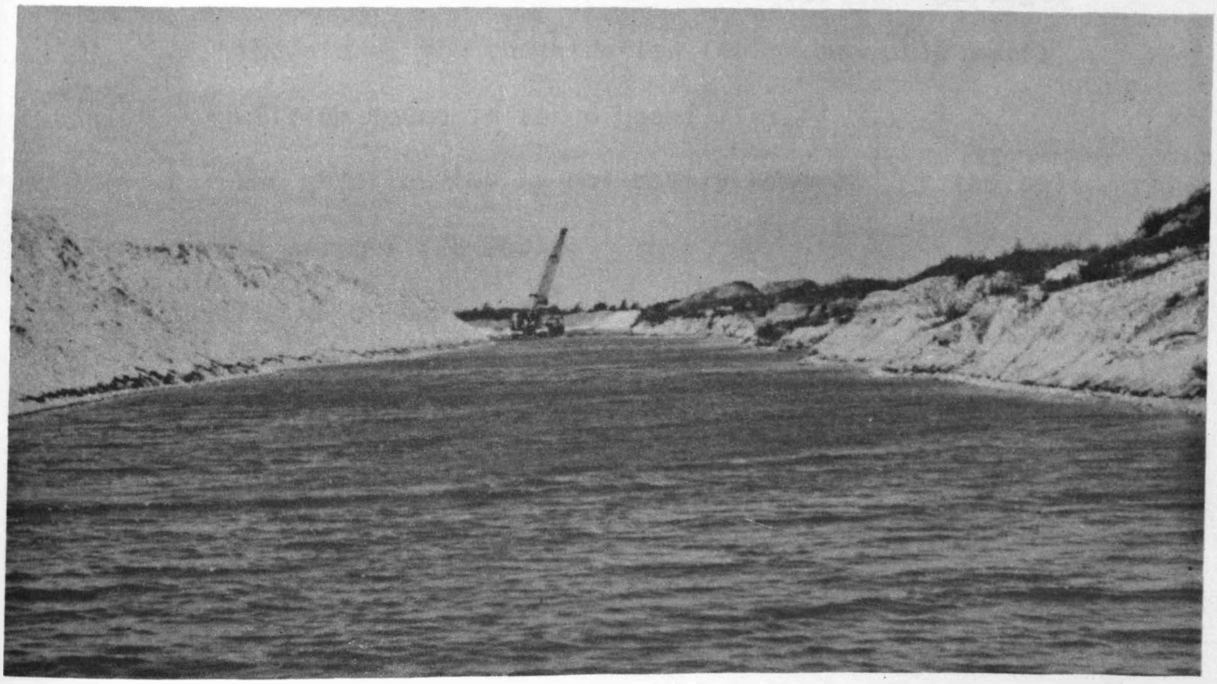

Figure 4. Intercepting trench at the Brookings refuse disposal area, looking west, June 1967.

that may be pertinent to this study. Refer to Figure 5 for the location of all the sampling points. Continuous records of water table levels were collected at wells 31, 29, and 27 with automatic float recorders. Daily rainfall records from the recording station at South Dakota State University were utilized along with rainfall measurements collected at the disposal area.

Selected Parameters

The four parameters selected for analysis during this research investigation (chloride, sodium, specific conductance, and total hardness) were recommended by McCormick (5-47) and Sawinski (6-35).

The chloride ion is possibly the most reliable indicator of leaching from a refuse landfill area for the following reasons:

1. Common table salt is present in household garbage; therefore, the chloride ion (anion of table salt) will be found in large quantities.
2. The chloride ion is not easily adsorbed by the soil formations (28-260).
3. The chloride ion is not altered or changed in quantity by biological processes (28-260).

It is significant to note that high concentrations of chloride in the ground water may have deleterious effects on agricultural plants (29-86).

The sodium ion is the cation associated with chloride in common table salt. Therefore, the sodium ion is probably the next

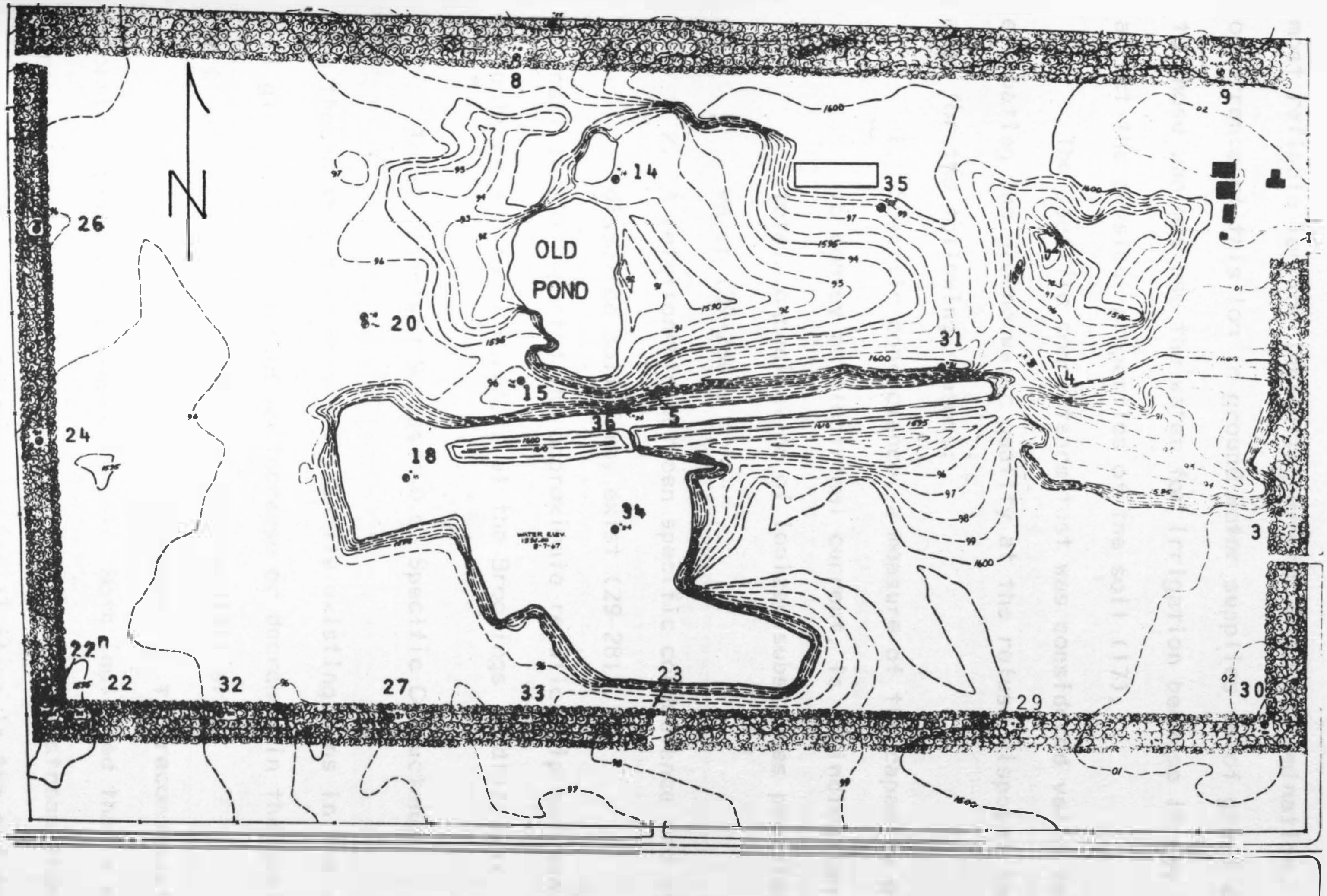

Figure 5. Topographic map of refuse disposal site showing the location of the sampling points, Brookings, South Dakota, 1967.

most reliable ion for indicating ground water contamination. The occurrence of this ion in ground water supplies is of great concern to those who may use the water for irrigation because it may adversely affect the physical properties of the soil (17).

The specific conductance test was considered valid for evaluating the ground water quality at the refuse disposal landfill area for the following reasons:

1. Specific conductance, a measure of the capacity of water to convey an electrical current, is an indication of the total concentration of ionized substances prevalent in water (29-280).
2. A relationship between specific conductance and total dissolved solids may exist (29-281).

Sawinski (6-38) reported the approximate relationship between specific conductance and total hardness at the Brookings landfill as:

Total Dissolved Solids = 0.65 Specific Conductance

Even though this test does not identify existing ions in the water, it will give an indication of an increase or decrease in the quality of the ground water passing through the landfill area.

Total hardness was selected because of the recommendations of McCormick (5-46) and Sawinski (6-68). Both indicated that a significant decrease in total hardness occurred within and downstream from the pond, possibly relative to the presence of algae in the old pond.

The four parameters were considered adequate to provide additional data pertaining to the influence of the intercepting trench on the quality of the ground water.

Sampling Procedures

Duplicate samples were obtained monthly (during November 1966 to August 1967) from the selected well points. During significant increases in the water table additional samples were collected. Before sampling, the water table elevations were measured from the top of the well casing with the aid of a cloth tape. The actual water table elevation was obtained by subtracting the measured value from the known elevation of the well casing. The wells were sampled with the aid of a centrifugal pump by first allowing the discharge of water from the pump for at least five minutes (depending on the pump rate) for elimination of the accumulated stagnate water in the well casing and for attainment of a sample visibly free of suspended soil particles. Upon completion of this step, duplicate samples were pumped into clean one-quart plastic bottles.

During the ten months of sampling, the peripheral points (those containing a lower degree of contamination) were sampled first, allowing the inner points (those containing the highest contamination) to be sampled last. Upon completion of sampling, the 26 duplicate samples were taken to the Water Resources Laboratory for analysis. Total hardness was determined immediately to prevent error due to precipitation of $CaCO_3$. The values of the other parameters were usually determined within three days.

Analytical Determinations

The concentrations of the four parameters previously mentioned were determined by using the procedures presented in the 12th edition of Standard Methods for the Examination of Water and Wastewater (20). Nevertheless, chloride and total hardness were determined by using the modifications presented in the Hach Chemical Company literature (30). The mercuric nitrate method was used for chloride and the EDTA titration method was used for total hardness. For the determination of specific conductance, an Industrial Instruments Type RC Conductivity Bridge was used. Two instruments, a Coleman model 21 emission flame photometer and an Universal spectrophotometer model 14, were used for determining sodium.

PRESENTATION AND DISCUSSION OF DATA

Influence of the Intercepting Trench and the New Excavation on Ground Water Flow

McCormick (5) and Sawinski (6) established and confirmed that the line of flow followed a southwest direction through the quarter section used by the City of Brookings for refuse disposal. Assuming the direction of flow is perpendicular to the ground water table contours, the direction of flow through the landfill area may be determined from Figure 6. The data used to establish water table contours were collected on June 15, 1966, prior to the construction of the trench. The water table contours existing after the construction of the intercepting trench may be observed in Figure 7. These data were obtained on June 3, 1967. All ground water elevation data may be found in tabular form in Appendix A.

Examination of Figure 7 reveals the effectiveness of the trench for attracting the ground water. This may be explained by the concept that water will follow the path of least resistance; it will flow in greater volumes through those sections which have the highest permeability (31-152). Figure 7 indicates that the ground water was entering the intercepting trench along the north side and the east end. The inflow of ground water together with the outflow (possibly at the southwest end) may aid in the mixing action in the intercepting trench. This may produce the only prevalent mixing action during the months that the surface of the trench is covered with ice. Ice-covering will prevent wind from increasing the mixing action within the intercepting trench.

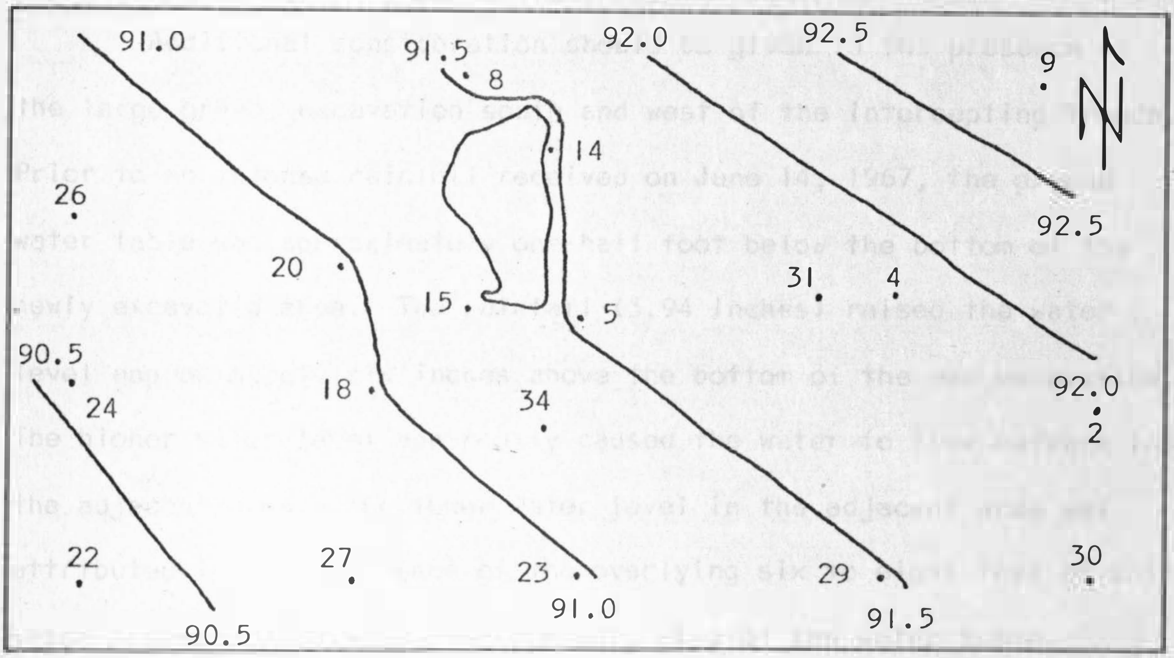

Figure 6. Water table contours at the Brookings landfill on June 15, 1966.

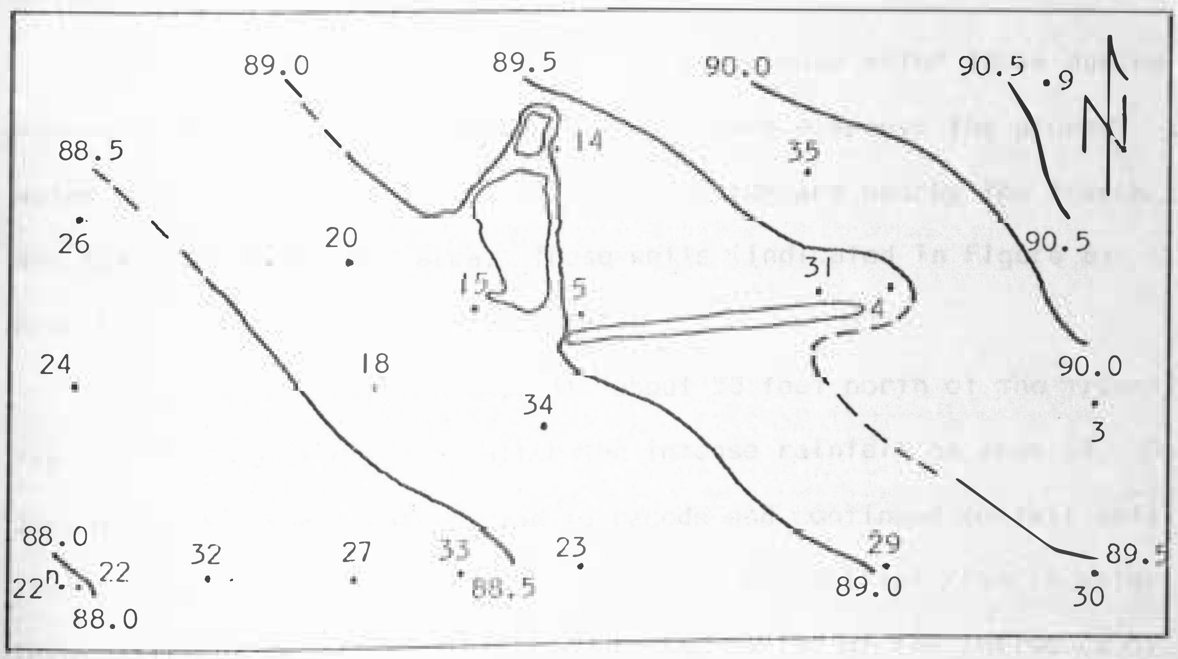

Figure 7. Water table contours at the Brookings landfill on June 3, 1967.

Additional consideration should be given to the presence of the large gravel excavation south and west of the intercepting trench. Prior to an intense rainfall received on June 14, 1967, the ground water table was approximately one-half foot below the bottom of the newly excavated area. The rainfall (3.94 inches) raised the water level approximately six inches above the bottom of the new excavation. The higher water level apparently caused the water to flow outward into the adjacent area. The lower water level in the adjacent area was attributed to the influence of the overlying six to eight feet of soil which probably prevented the immediate rise of the water table. Furthermore, this outward flow of water probably provided additional dilution which decreased the degree of contamination within the adjacent ground water.

The effects of this rainfall on the ground water table during June can be observed in Figure 8. This figure displays the ground water elevations at wells 31, 29, and 27 which are nearby the trench and the newly excavated area. These wells (indicated in Figure 8) have continuous water level recorders.

The water level in well 31, about 50 feet north of the trench, rapidly rose about one foot after the intense rainfall on June 14. On June 15, the water level started to recede and continued to fall until June 18 when additional rainfall occurred. The initial rise in water level followed by an abrupt decline is indicative of the influence of the trench. It appears that the trench discharged flow to the water table of the adjacent area during the rainfall, and the flow was

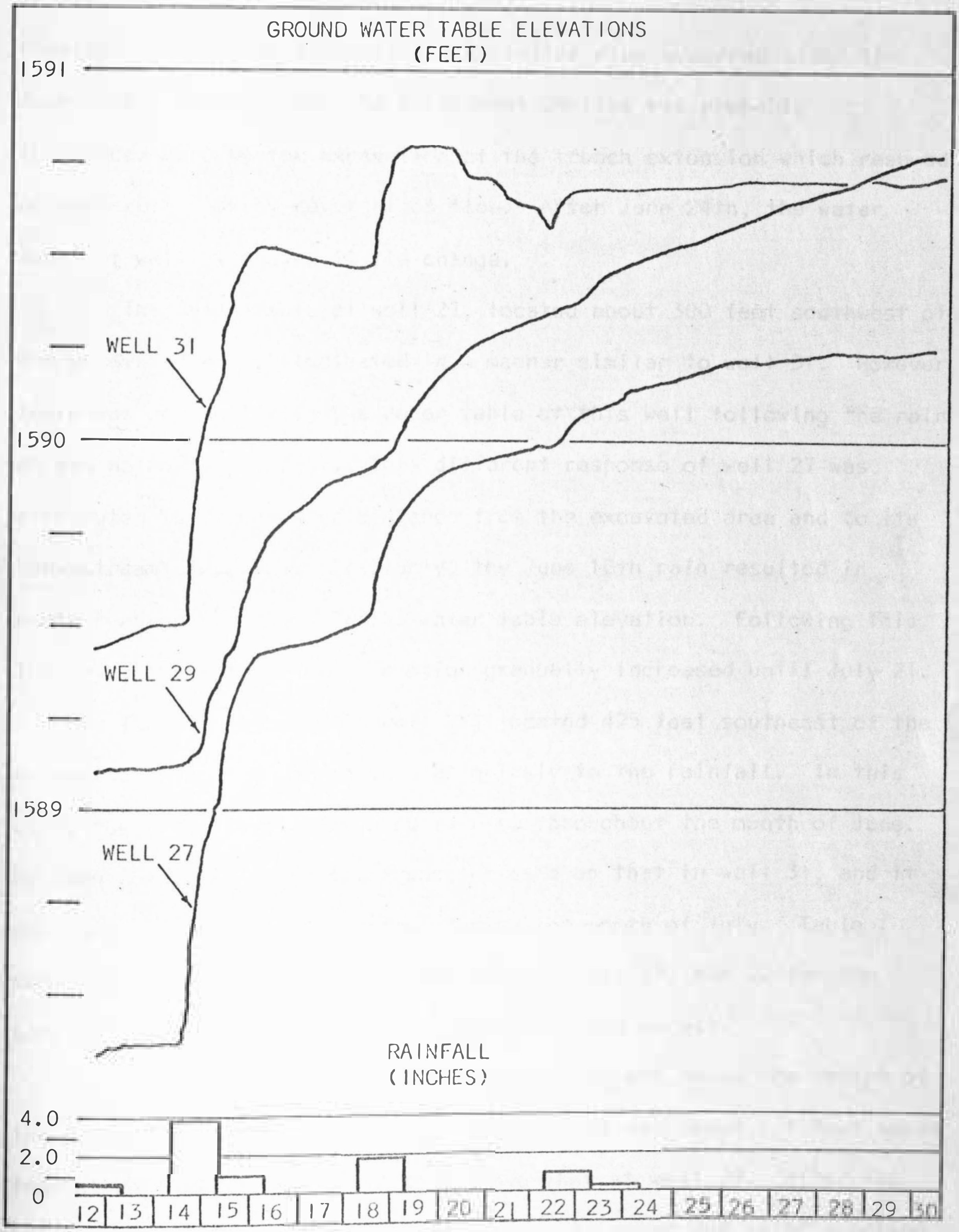

Figure 8. Ground water elevations at selected wells and recorded rainfall at the Brookings refuse disposal area, June 12-30, 1967.

reversed immediately thereafter. A similar rise occurred after the June 18th rain; however, the subsequent decline was probably influenced more by the excavation of the trench extension which resumed on June 20th than by reversal of flow. After June 24th, the water level at well 31 showed little change.

The water table at well 27, located about 300 feet southwest of the excavated area, fluctuated in a manner similar to well 31. However, there was no decline in the water table at this well following the rain as was noted for well 31. This different response of well 27 was attributed to its greater distance from the excavated area and to its "downstream" location. Similarly, the June 18th rain resulted in another abrupt increase in the water table elevation. Following this increase, the water table elevation gradually increased until July 21.

The water levels in well 29, located 425 feet southeast of the excavated area, did not respond as quickly to the rainfall. In this case, the water level continued to rise throughout the month of June. By June 28th, the water level was the same as that in well 31, and it maintained this higher elevation during the month of July. Table I contains recorded water elevations at wells 31, 29, and 27 for the same dates during the months of June, July, and August.

On June 13, 1967, when the water table was below the bottom of the excavated area, the water level at well 31 was about 1.1 feet above that at well 27 and about 0.4 feet above that at well 29. After the bottom of the excavated area was covered with water and after a period of reduced rainfall (during July and August 1967), the water level

Table I. Water table elevations at well 31, 29, and 27 for various dates during the months of June, July, and August 1967.

Date	Water Table Elevations 1500 + tabular value (Feet) Well 31	Well 29	Well 27
June 13	89.47	89.11	88.36
June 16	90.52	89.77	89.44
June 25	90.69	90.57	90.15
June 28	90.70	90.70	90.24
July 4	90.73	90.87	90.29
July 10	91.07	91.10	90.45
July 20	91.11	91.27	90.61
July 30	91.11	91.27	90.53
August 19	90.97	91.04	90.33

difference between wells 31 and 27 was only about 0.5 to 0.6 feet. After June 28th, the relative water table elevations at wells 31 and 29 were significantly changed. The water table levels at well 29 were above those at well 31; previously they had been below those at well 31. Considering these relative changes in water table elevation at the wells adjacent to the trench and the excavated area, it appears that the entire pattern of underground water flow in this area was altered.

Mixing in the Intercepting Trench and the Old Pond

Because highly significant differences in ground water quality had been found between the various wells at the refuse disposal area (5), (6), it was expected that the ground water seeping into the trench at various points would also differ in quality. These studies had shown that the native water (well 9) was consistently lower in ionic concentration than that found close to the active fill area (well 5). Thus, if the trench were to intercept and to enhance the degraded ground water before it moved downstream, mixing with a higher quality water would be one of the necessary factors. Aeration for removal of entrained gases and algal effects within the trench may also be expected to enhance the water quality.

In order to determine if mixing were occurring, samples were collected at several points in the trench and the old pond. Two samples were collected from the old pond at the north and south ends, and two samples were obtained from the intercepting trench from the west end, middle, and east end. Seven sets of samples were collected on seven dates during the period from January to July 1967, for the determination of chloride, sodium, specific conductance, and total hardness. The results of these analyses are included in Appendix B.

Table 2 reports the mean values obtained for each of the parameters at the different sampling locations. From this table, it can be seen that the average concentrations of the parameters at the two sampling locations in the old pond were substantially different. The south end of the old pond had consistently higher concentrations than

Table 2. Mean values of parameters at sampling locations in the trench and old pond, January - July 1967.

Sampling Location	Chloride (mg/l)	Sodium (mg/l)	Specific Conductance (Micromhos at 25°C)	Total Hardness (as mg/l of $CaCO_3$)
Old Pond				
North End	74.5	57.0	816	297.9
South End	133.8	92.7	1088	344.0
Trench				
West End	16.5	16.9	676	327.3
Middle	16.5	16.6	671	320.7
East End	15.8	16.5	667	320.7

the north end. On the other hand, the average concentrations in the trench were nearly the same for each of the three locations. A similar pattern occurred on each of the dates samples were collected (Appendix B). From these data, it can be interpreted that the longer and deeper trench probably afforded greater mixing than the pond even during the periods when ice cover occurred.

Ground Water Quality Changes from 1966 to 1967

The quality changes noted in the ground water at the Brookings landfill area from November 12, 1966 - July 1, 1967, cannot be solely related to the intercepting trench. Consideration has to be made of four additional physical changes that occurred during this investigation period. The physical factors that may have contributed to the quality changes of the ground water can be listed as: the existence of an intercepting trench which possibly altered the flow pattern of the ground water; the excavated area to the south and west of the trench; a generally lower water table throughout the landfill area; deposition of refuse at different sites within the general landfill area; and the formation of ice on the surface of the trench.

It has been shown that the intercepting trench influenced the flow pattern of the ground water at the Brookings landfill area. This change in flow pattern was revealed by the examination of the water table elevations in Table I. However, sufficient data were not available to define accurately this new pattern. Nevertheless, it was assumed that the ground water would flow in directions different than those shown by previous investigations. The ground water quality at the various well locations may have been either degraded or enhanced.

The excavation to the south and west of the trench possibly did not affect the quality of the ground water until after the heavy rains which occurred about June 14th causing the water table to rise approximately 1.5 feet above the bottom of the excavated area. The water elevation in the excavation was possibly higher than the water table elevation in the adjacent areas. This condition may have caused the water to flow outward from the excavated area thereby possibly diluting the adjacent ground water. Furthermore, this additional volume of water may have altered the gradient of the water table.

Water table elevations during this period of study were substantially lower than those during Sawinski's period of study.

During the period October 30, 1965 to June 15, 1966, the water table elevations at wells 5 and 14 ranged from 1590.20 to 1591.58 feet (6-92). During the period of this study from November 12, 1966, to just prior to the June 14th rainfall, the range of the water table elevations at these same wells was from 1589.13 to 1589.76 feet. Thus, the water table in the area of active refuse disposal (wells 5 and 14) was generally 1.0 to 1.5 feet lower during the period of this study. As a result, the ground water may not have been in contact with as much of the refuse that had been deposited throughout the old gravel pit area. This would be expected to reduce the leaching from this source (12-13).

The active disposal sites that were used during this period of investigation were different than those sites utilized during the 1965-1966 investigation. From October 30,1965 to June 15, 1966, the major portion of refuse was deposited approximately 60 feet northeast of well 14 (located on the northeast side of the old pond). From November 12, 1966 to July 1, 1967, the refuse was deposited at three points: 100 feet north of well 5 (located north of the west end of the trench); approximately 260 feet east of well 14; and about 500 feet northeast of well 31. As a result, more active leaching at these new disposal sites could be expected. Thus, the ground water in the vicinity of the new disposal sites would possibly be more degraded. The opposite may be true at the old site.

Sawinski (6-58) indicated that the formation of ice-covering on the surface of the old pond may have resulted in increased ionic concentrations in the old pond during the winter months. Thus, the additional ice-covering on the surface of the trench may also result in increased ionic concentrations in the trench during the winter months. With the melting of the ice, dilution and reduction of ionic concentrations would be expected. Considering these five physical variables, the data collected from November 12, 1966 to July 1, 1967 were compared with the data collected from February 5, 1965 to June 15, 1966. Figure 9 shows the variations in chloride concentrations at well 5 and well 14 for this period. This figure shows that the chloride content at wells 5 and 14 has been substantially lower during the last year. This reduction in chloride content appears to reverse the trend of increased ionic concentrations noted by Sawinski (6-54, 67).

Further comparisons between the data collected from October 1965 to June 1966 (Sawinski's study) and that collected from November 1966 to July 1967 may be made by referring to Table 3. This table contains the mean concentrations for several parameters at selected sampling points during the two periods.

From Table 3, it can be seen that the mean concentrations of the reported constituents in the water at wells 9 and 3 (control wells) have slightly increased since the 1965 - 1966 investigation. The water quality at wells 8 and 29, which are laterally displaced along the general path of ground water flow from the active disposal area, has not changed since the 1965 - 1966 investigation.

Examination of the mean concentration values for the old pond and well 14 revealed that the quality of the water has been improved

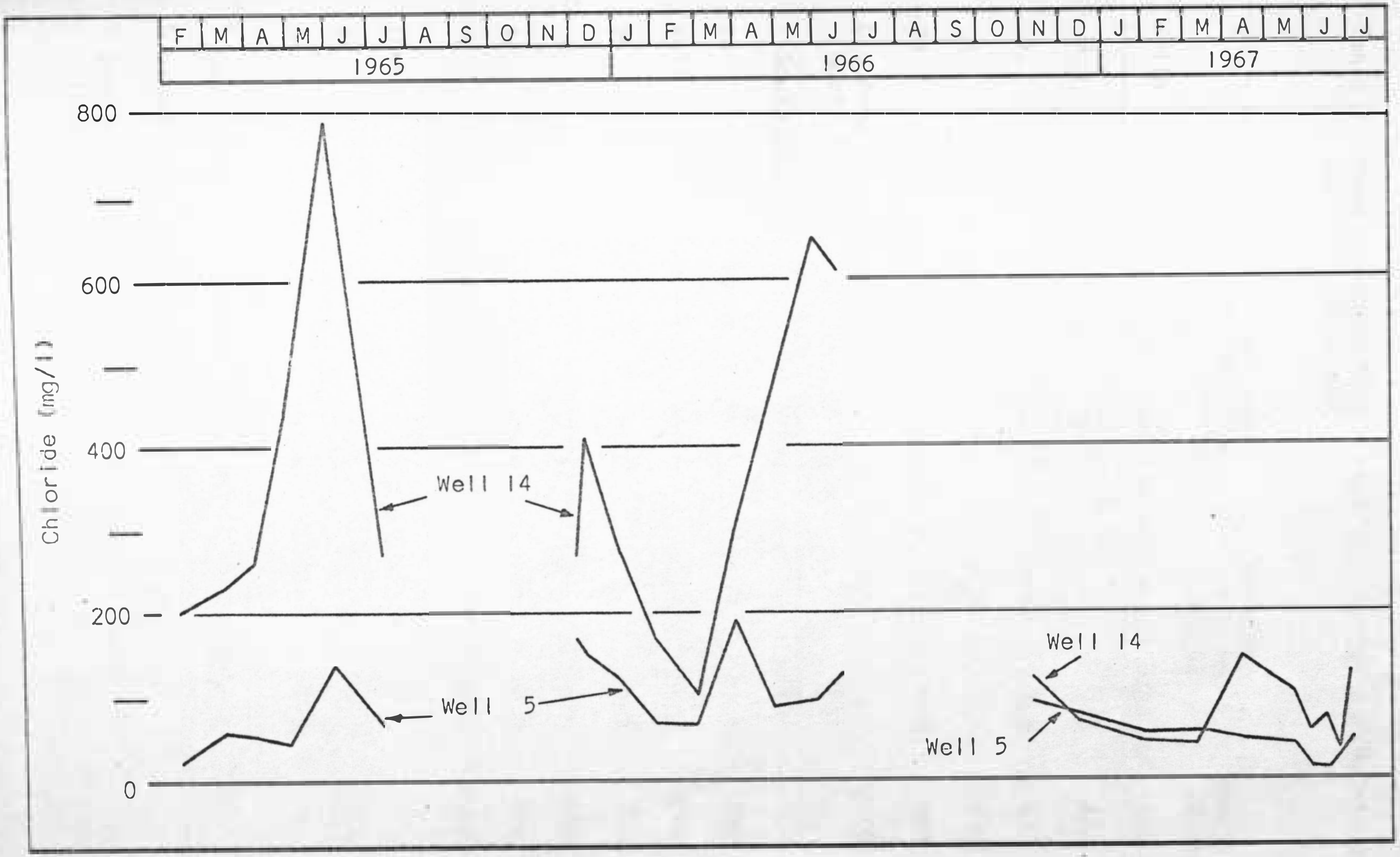

Figure 9. Variations in Chloride Concentrations for Wells 14 and 5 from February 1965 to July 1967.

Table 3. Mean concentration values for several parameters at selected sampling locations.

Wells	Average Total Hardness (as mg/l of $CaCO_3$) 1965-66[a]	1966-67[b]	Average Chloride (mg/l) 1965-66[a]	1966-67[b]	Specific Conductance (Micromhos at 25°C) 1965-66[a]	1966-67[b]
9	245.6	301.8	4.2	5.5	464	595
3	298.2	301.1	3.9	3.9	573	586
8	345.1	341.6	8.9	8.5	672	687
29	304.2	292.9	4.4	4.2	583	572
Old Pond	384.2		154.1		1110	
North End		297.9		74.5		816
South End		344.0		133.8		1088
14	427.8	318.6	360.8	87.6	1825	956
15	449.1	405.4	156.3	139.9	1066	1104
20	378.9	349.8	17.2	13.4	744	705
4	325.1	377.5	10.1	6.1	655	731
31	393.4	410.0	14.9	21.2	756	800
5	525.1	622.4	120.4	50.7	1326	1237
Trench		322.9		16.3		671
27	520.1	477.2	60.6	58.5	1030	996
23	400.2	399.5	19.3	17.2	755	775

[a] Sawinski's study from October 30, 1965 to June 15, 1966.

[b] November 12, 1966 to July 1, 1967.

[c] Sawinski sampled well 2 instead of well 3 which were approximately 15 feet apart.

at both sampling locations since 1965 - 1966. This enhancement could possibly be attributed to the lower water table or to the change of the flow pattern of the ground water. This flow pattern may now be from the deposited refuse towards the intercepting trench instead of towards the old pond as was possible from October 30, 1965 to November 12, 1966.

Examination of the mean concentration values for well 15 and well 20 also indicated a slight enhancement of the water quality during the latter study. This improvement may be attributed to the lower water table or to the trench which may have attracted native ground water from the northwest corner of the landfill. This native water may have diluted the ground water in the vicinity of wells 20 and 15.

A different result may be revealed by the examination of the mean concentrations at wells 4, 31, and 5. Considering these three wells along the north edge of the trench, it can be noted that for both periods the ionic concentrations were lowest at well 4, higher at well 31, and highest at well 5. Thus, if the trench were intercepting ground water flow from the disposal area to the north, the most degraded water was probably being intercepted near well 5.

Upon comparing the mean concentration values for the trench with those values for wells 4, 31, and 5, it can be seen that the water in the trench was of substantially better quality. This improvement may have been attributed to the dilution and dispersion caused by the mixing that occurred in the trench.

At well 31, the slight degradation of the water quality that occurred during 1967 may have been related to the refuse that was deposited north of this well since the previous study.

The total hardness increase revealed at well 5 may have resulted from ice formation in the ground north of well 5. During the winter months, the ground which has a low surface elevation may have frozen, possibly concentrating the ionic constituents in the ground water of that area. Because of the slow velocity of the ground water (1 - 3 feet per day), this high concentration would possibly not flow through the vicinity of well 5 until March or April 1967. In addition, the low chloride content which occurred at well 5 may have been attributed to the effects of the low water table.

Examination of the mean ionic concentrations in Table 3 for wells 27 and 23 showed that little change has occurred in the quality of the ground water between study periods. This may have been attributed to the velocity of the ground water (1 - 3 feet per day). Since wells 27 and 23 are located approximately 600 feet south of the trench, the enhanced water from the trench would probably not flow through the vicinity of these wells until September or October 1967.

In summary, it appears that the ground water quality in the vicinity of the old pond and the well located generally northwest of the trench has improved since the trench was constructed. The water in the trench was also found to be of substantially higher quality than the ground water at those wells between the active fill area and the trench. Thus, if the trench has been adequately intercepting this ground water, it appears to have been enhancing the quality. Little change in water quality has occurred at those wells along the south side of the excavated area where the degraded water has been leaving the landfill site. Perhaps sufficient time has not yet elapsed to make the influence of the trench apparent at these more distant downstream wells.

Statistical Analysis

Duplicate samples were obtained and analyzed in order to analyze statistically the data and to make a comparison with Sawinski's (6) investigation. It was decided to make an analysis of variance of locations, dates, and location by date interaction at the one percent level. These analyses (Appendix C) would then indicate those areas of statistical significance for this investigation. The results of the analyses were:

1. Locations were highly significant i.e., there were highly significant differences between wells.
2. Dates were highly significant i.e., there were highly significant differences in the quality of the water samples between the sampling dates.
3. The location by date interaction was highly significant. While there are well differences within the same date and the quality of water in the wells differs on different dates, the wells do not variate the same from date to date. That is, as the concentration of ions increased in

the ground water within the vicinity of some wells, the concentrations of ions decreased in the ground water within the vicinity of other wells.

These interpretations were in agreement with those made by Sawinski.

CONCLUSIONS

The conclusions of this investigation can be stated as:

1. The evaluation of the data revealed that the intercepting trench improved the quality of the degraded ground water flowing from the fill area. This enhancement may not be noticed at wells 23 and 27 until September or October 1967. The intercepting trench may further improve the quality of the ground water now that the trench has been constructed to extend the complete length of the south edge of the refuse disposal area.
2. Examination of the mean concentration values for the sampling locations in the intercepting trench revealed that mixing was occurring within the trench.
3. The intercepting trench and the excavated adjacent area altered the flow pattern of the ground water in the vicinity of the refuse disposal area.
4. During this investigation period, the quality of the water in the vicinity of the old pond, and wells 14, 15, and 20 has improved from 1966 to 1967.
5. The statistical interpretations of the data were in agreement with those made by Sawinski (6).

RECOMMENDATIONS

Although several conclusions have been drawn from this investigation, several recommendations can be suggested for continuing related and new projects. These are listed as:

1. More sampling wells should be installed within the area adjacent to the new trench and to the large gravel excavation to collect more data concerning changes in water quality and water table elevations.
2. Even though the new trench has been extended westward along the south side of the landfill area, consideration should be given to the possibility of extending the new trench northward along the west side of the landfill area. This would provide an ideal situation for optimizing the beneficial effects of the intercepting trench on the quality of the ground water flowing from the refuse disposal area.
3. Research may be considered to study the exact flow rate and flow pattern of the ground water in the total area of the landfill. This would provide the additional data needed to correlate the quality changes with the downstream movement of the water.
4. Consideration should be given to the utilization of artificial aeration in the intercepting trench to improve the quality of the degraded ground water flowing from the vicinity of the refuse landfill.

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APPENDIX A

Water Table Elevations

Water Table Elevations at Sampling Locations

1500 + tabular value

Well	11-12-66	12-17-66	1-27-67	3-11-67	3-18-67	3-23-67	4-8-67
3	90.09	89.88	89.75	89.77			89.90
4	89.89	89.49	89.43	89.54	89.48	89.55	89.59
5	89.33	89.29	89.13	89.36	89.31	89.39	89.44
8	89.88	89.64	89.53	89.81			89.74
9	90.98	90.71	90.52	90.69	90.62	90.72	90.67
14	89.79	89.59	89.45	89.76			89.69
15	89.07	88.78	88.78	88.94	88.92	88.99	89.06
18	88.88	88.65	88.50	88.69			88.77
20	88.82	88.75	88.63	88.79			88.94
22	88.22	87.99	87.84	87.97	87.95	88.01	88.09
23	88.83	88.62	88.47	88.54			88.66
24	88.44	88.23	88.08	88.28			88.40
27	88.53	88.35	88.20	88.26	88.25	88.31	88.34
29	89.22	89.04	89.09	88.97			89.09
30	89.57	89.42	89.24	89.34			89.47
31	89.73	89.40	89.34	89.44			89.54
32				88.10			88.20
33				88.43			88.50
35				90.05			89.82

Water Table Elevations (continued)

Well	5- 6-67	6- 3-67	6-15-67	6-17-67	6-22-67	7- 1-67
3	89.94	89.78	90.27	90.72	91.18	91.58
4	89.51	89.36	90.29	90.59	90.66	90.85
5	89.35	89.17	89.96	90.30	90.41	90.63
8	89.61	89.39	90.59	91.23	91.34	91.20
9	90.66	90.62	90.99	91.66	92.11	92.36
14	89.55	89.28	91.09	90.76	90.91	90.91
15	88.94	88.72	89.85	89.99	90.30	90.56
18		88.60	89.78	89.94		90.66
20	88.85	88.67	89.85	90.24	90.69	90.58
22	88.15	87.99	88.77	89.35	90.07	90.24
23	88.66	88.55	89.36	89.74	90.15	90.46
24	88.38	88.19	88.99	89.89	90.42	90.40
27	88.41	88.32	88.88	89.45	90.00	90.25
29	89.11	89.05	89.32	89.97	90.35	90.79
30	89.48	89.45	89.68	90.18	90.74	91.25
31	89.48	89.32	90.11	90.52	90.60	90.73
32	88.24	88.09	88.80	89.42	90.02	90.29
33	88.53	88.43	89.16	89.66	90.09	90.40
35	89.75	89.58	90.59	90.87	91.09	91.11

APPENDIX B

Ground Water Quality Data

Means of Chloride

(mg/l)

Well	11-12-66	12-17-66	1-27-67	3-11-67	4- 8-67	5- 6-67	6- 3-67	6-17-67	7- 1-67	Location Mean
3	3.0	3.7	3.2	3.7	4.0	4.1	4.1	4.2	4.4	3.9
4	4.7	4.2	5.5	5.3	6.7	6.9	6.5	6.6	8.0	6.1
5	94.0	78.0	57.1	58.4	50.8	40.9	15.9	15.8	45.7	50.7
8	8.7	7.5	8.2	8.0	8.7	8.7	8.7	8.9	9.0	8.5
9	5.0	5.3	5.5	5.5	6.1	5.5	5.3	6.3	5.0	5.5
14	121.2	70.5	45.0	40.7	146.2	101.2	60.0	76.3	127.5	87.6
15	131.7	172.0	183.2	167.8	141.4	136.9	119.4	109.2	97.7	139.9
18	48.0	40.5	43.5	51.2	48.0		136.0	135.8	138.0	80.1*
20	14.9	12.9	13.5	13.5	13.4	13.3	12.9	12.9	13.1	13.4
22	26.1	24.6	26.0	34.0	25.9	24.3	24.7	27.4	26.5	26.6
23	20.0	19.3	17.5	15.9	16.5	16.5	15.5	15.7	17.5	17.2
24	5.5	6.7	7.0	7.2	7.6	7.6	7.0	7.5	7.9	7.1
27	72.7	74.6	69.1	51.5	53.8	51.0	48.6	42.9	62.0	58.5

Chloride (continued)

Well	11-12-66	12-17-66	1-27-67	3-11-67	4-8-67	5-6-67	6-3-67	6-17-67	7-1-67	Location Mean
29	7.0	2.7	3.6	3.5	4.2	4.0	4.5	3.9	4.0	4.2
30	7.5	5.4	6.0	6.0	7.2	7.0	7.0	7.0	7.5	6.7
31	18.6	17.0	26.5	24.0	23.9	22.7	20.0	19.0	18.5	21.2
32				110.1	126.0	115.9	107.4	102.2	126.4	115.1*
33				27.5	27.5	26.7	26.5	26.2	27.8	27.5*
35				8.5	9.1	9.2	9.4	8.7	9.6	9.5*
Date Mean	39.5*	36.8*	35.2*	33.8	38.3	35.9*	33.7	33.5	39.8	

*This mean was calculated by using the Least-square method.

Means of Sodium

(mg/l)

Well	11-12-66	12-17-66	1-27-67	3-11-67	4- 8-67	5- 6-67	6- 3-67	6-17-67	7- 1-67	Location Mean
3	10.7	9.9	10.5	8.8	8.8	9.8	6.3	6.7	8.7	8.9
4	13.0	10.8	9.8	9.0	10.2	9.8	7.0	8.3	10.0	9.8
5	97.7	84.8	52.2	49.9	52.3	47.7	17.4	15.8	42.6	51.1
8	16.2	14.8	13.7	12.8	12.3	14.0	9.8	11.2	13.6	13.2
9	7.9	7.1	8.8	8.1	8.8	8.7	5.9	6.3	7.5	7.7
14	87.5	59.9	44.8	36.0	88.6	78.1	45.0	39.9	58.9	59.9
15	81.4	77.8	81.2	87.8	88.4	75.8	76.4	88.2	75.3	81.3
18	20.3	16.6	18.5	17.9	17.3		70.4	72.6	74.8	38.7*
20	18.3	15.9	16.2	15.2	15.8	15.8	12.3	12.1	13.8	15.1
22	18.0	16.5	15.8	16.4	15.9	16.5	12.4	14.4	16.6	15.8
23	19.3	14.0	16.7	16.4	15.9	15.7	12.4	11.2	15.7	15.3
24	12.7	10.2	11.6	11.6	11.6	11.7	8.7	8.4	9.0	10.6
27	46.1	37.2	36.1	36.7	38.4	35.0	28.7	28.7	35.2	35.8

Sodium (continued)

Well	11-12-66	12-17-66	1-27-67	3-11-67	4- 8-67	5- 6-67	6- 3-67	6-17-67	7- 1-67	Location Mean
29	9.9	7.0	9.0	8.4	8.4	8.8	6.2	5.7	8.7	8.0
30	9.6	7.5	8.2	8.4	9.1	8.7	5.6	5.5	7.4	7.8
31	17.5	13.9	15.4	17.1	19.6	19.8	16.5	16.3	19.2	17.3
32				30.9	37.6	39.8	33.0	32.6	40.5	36.5*
33				25.7	27.0	26.9	20.7	23.0	25.5	25.5*
35				14.4	14.7	14.6	11.0	11.2	12.4	13.8*
Date Mean	30.5*	25.4*	23.1*	22.7	26.4	26.2*	21.4	22.0	26.1	

*This mean was calculated by using the Least-square method.

Means of Specific Conductance

(Micromhos at 25°C)

Well	11-12-66	12-17-66	1-27-67	3-11-67	4- 8-67	6- 3-67	6-17-67	7- 1-67	Location Mean
3	573	586	593	588	593	584	583	584	586
4	610	606	707	701	755	753	814	901	731
5	1240	1090	1295	1536	1631	797	768	1540	1237
8	670	668	677	676	763	682	680	680	687
9	569	586	605	610	625	554	612	602	595
14	1010	915	838	822	1120	925	933	1085	956
15	1005	1082	1155	1199	1148	1200	1062	976	1104
18	724	708	712	751	755	974	968	983	822
20	689	684	713	712	714	707	704	712	705
22	641	656	674	701	754	684	711	706	691
23	819	817	792	762	765	758	753	734	775
24	611	642	651	652	662	668	666	681	654
27	1121	1051	1092	984	973	923	883	937	996

Specific Conductance (continued)

Well	11-12-67	12-17-67	1-27-67	3-11-67	4- 8-67	6- 3-67	6-17-67	7- 1-67	Location Mean
29	565	581	576	569	570	569	569	578	572
30	618	606	626	613	622	620	618	626	619
31	719	731	782	802	806	813	813	935	800
32				915	978	935	911	1012	939*
33				833	820	814	815	854	816*
35				731	745	742	710	723	719*
Date Mean	768*	757*	787*	798	832	774	767	834	

*This mean was calculated by using the Least-square method.

Means of Total Hardness

(as mg/l of $CaCO_3$)

Well	11-12-66	12-17-66	1-27-67	3-11-67	4- 8-67	5- 6-67	6- 3-67	6-17-67	7- 1-67	Location Mean
3	298.4	302.3	298.2	303.4	303.0	301.2	300.2	300.1	302.6	301.1
4	311.2	307.1	326.1	366.0	386.4	380.2	395.0	440.0	485.2	377.5
5	540.0	470.1	618.0	800.0	851.8	855.1	362.2	346.0	758.0	622.4
8	338.0	334.7	330.2	340.7	344.1	347.6	345.2	348.1	345.6	341.6
9	293.0	292.1	301.1	314.3	320.1	298.1	274.1	315.0	308.9	301.8
14	274.5	291.0	263.1	303.0	331.7	305.9	332.4	355.6	410.1	318.6
15	393.0	421.5	402.0	433.9	427.4	419.2	406.2	391.1	353.9	405.4
18	354.5	346.0	342.0	352.1	356.1		340.0	335.0	338.0	347.1*
20	356.4	348.3	347.0	346.0	352.3	352.3	347.9	347.9	349.9	349.8
22	316.5	308.4	316.1	331.0	334.1	334.2	335.9	349.9	348.0	330.5
23	445.0	429.0	401.0	386.0	398.4	389.0	390.5	378.1	379.1	399.5
24	312.5	324.0	322.0	326.0	335.9	335.5	340.1	342.9	340.9	331.1
27	558.3	547.0	521.0	466.0	462.9	440.1	440.0	419.7	442.0	477.2

Total Hardness (continued)

Well	11-12-66	12-17-66	1-27-67	3-11-67	4-8-67	5-6-67	6-3-67	6-17-67	7-1-67	Location Mean
29	292.0	296.0	290.0	292.0	290.7	289.2	297.0	292.0	297.0	292.9
30	321.5	318.0	309.3	319.0	308.1	316.7	312.0	319.1	320.0	316.0
31	370.0	372.0	396.1	409.4	407.9	413.8	416.0	414.1	490.2	410.0
32				417.7	428.3	421.5	413.0	406.4	436.9	415.4*
33				413.0	411.9	411.7	399.6	406.6	424.0	406.0*
35				380.8	387.8	394.1	389.1	369.9	372.2	377.1*
Date Mean	365.4*	361.4*	366.1*	384.2	391.5	387.7*	359.8	362.0	394.9	

*This mean was calculated by using the Least-square method.

Means of Parameters for Sampling Locations
in the Old Pond and Intercepting Trench

Parameter and Location	1-27-67	3-11-67	4-8-67	5-6-67	6-3-67	6-17-67	7-1-67	Location Mean
Chloride (mg/l)								
Old Pond								
North End	153.0	54.0	66.1	67.9	72.0	48.1	60.1	74.5
South End	227.9	242.1	111.9	110.2	107.0	75.2	62.0	133.8
Trench								
West End	21.2	16.0	14.2	13.0	12.5	10.5	27.9*	16.5
Middle	20.1	18.0	16.0	12.9	12.0	11.1	25.2	16.5
East End	19.0	16.0	15.6	13.0	12.2	10.8	24.2	15.8
Sodium (mg/l)								
Old Pond								
North End	95.4	50.8	51.8	57.0	54.0	45.1	45.1	57.0
South End	140.0	164.8	79.5	82.0	83.2	54.2	45.2	92.7
Trench								
West End	21.1	18.1	15.9	16.5	13.4	10.8	22.4*	16.9
Middle	20.0	18.4	15.9	16.0	12.4	10.8	22.5	16.6
East End	20.7	18.6	15.9	15.9	11.7	10.6	22.0	16.5

Means of Parameters (continued)

Parameter and Location	1-27-67	3-11-67	4- 8-67	5- 6-67	6- 3-67	6-17-67	7- 1-67	Location Mean
Specific Conductance (Micromhos at 25°C)								
Old Pond								
North End	1316	822	736		731	638	650	816
South End	1471	1587	959		1028	795	685	1088
Trench								
West End	850	788	641		600	545	633*	676
Middle	846	783	641		600	549	606	671
East End	840	784	642		593	545	600	667
Total Hardness (as mg/l of $CaCO_3$)								
Old Pond								
North End	458.1	333.1	270.0	303.9	272.0	223.7	224.4	297.9
South End	425.0	475.0	315.8	333.9	349.0	267.9	241.1	344.0
Trench								
West End	412.0	401.1	322.0	296.2	287.9	260.1	312.1*	327.3
Middle	410.0	400.4	324.0	297.9	282.2	264.0	266.3	320.7
East End	410.0	402.1	319.9	298.1	284.1	260.9	270.1	320.7

*This sample was obtained approximately 10 feet below the depths from which the other two trench samples were obtained.

Means of Several Parameters for Weekly
Samples Collected at Selected Locations

Parameter and Date	Location 4	5	9	15	22	27	31	Old Pond North	Old Pond South
Chloride (mg/l)									
3-18-67	6.7	57.8	6.0	183.9	27.7	54.9		88.0	108.0
3-23-67	6.7	53.9	6.0	162.5	26.9	53.2		156.9	159.1
6-22-67	7.0	28.0	8.4				18.5		
8- 8-67		42.0	2.3			62.5	18.3		
Specific Conductance (Micromhos at 25°C)									
3-18-67	742	1589	625	1220	682	995		964	963
3-23-67	762	1581	621	1223	681	986		1300	1252
6-22-67	831	975	619				814		
8- 8-67		1384	439			958	844		
Total Hardness (as mg/l of $CaCO_3$)									
3-18-67	386.0	817.1	315.9	443.0	331.0	475.8		352.3	333.2
3-23-67	397.5	812.9	314.4	442.0	334.1	470.1		466.1	302.0
6-22-67	447.8	457.9	319.0				419.0		
8- 8-67		667.0	226.1			461.9	467.0		

APPENDIX C

Analyses of Variance

Analysis of Variance of Parameters
for Samples Collected at Wells

Total Hardness

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Locations	18	1,918,319.70	106,573.31	69,655.7**
Dates	8	59,978.44	7,497.31	4,900.2**
Loc x Date	134	796,221.42	5,941.95	3,883.6**
Error	161	246.54	1.53	
Total	321	2,774,766.10		

Sodium

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Locations	18	136,444.18	7,580.23	42,112.4**
Dates	8	2,239.06	279.88	1,554.9**
Loc x Date	134	28,796.35	214.90	1,193.9**
Error	161	28.37	0.18	
Total	321	167,507.96		

Analysis of Variance (continued)

Specific Conductance

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Locations	18	9,480,921.50	526,717.86	204,154.2**
Dates	7	218,836.53	31,262.36	12,117.2**
Loc x Date	117	2,236,612.47	19,116.30	7,409.4**
Error	143	369.50	2.58	
Total	285	11,936,740.00		

Chloride

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Locations	18	504,961.24	28,053.40	133,587.6**
Dates	8	1,777.14	222.14	1,057.8**
Loc x Date	134	80,042.84	597.33	2,844.4**
Error	161	33.79	0.21	
Total	321	586,815.01		

**Denotes significance at the 1% level

Analysis of Variance of Parameters
for Samples Collected from
the Pond and the Intercepting Trench

Specific Conductance

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Locations	4	1,574,523.40	393,630.85	492,038.5**
Dates	5	1,672,673.60	334,534.72	418,168.4**
Loc x Date	20	713,673.40	35,683.67	44,604.5**
Error	30	24.00	0.80	
Total	59	3,960,894.40		

Total Hardness

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Locations	4	15,335.51	3,833.88	5,399.8**
Dates	6	257,291.10	42,881.85	60,396.9**
Loc x Date	24	33,382.32	1,390.93	1,959.1**
Error	35	24.94	0.71	
Total	69	306,033.86		

Analysis of Variance (continued)

Sodium

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Locations	4	65,851.53	16,462.88	65,851.5**
Dates	6	8,914.93	1,485.82	5,943.3**
Loc x Date	24	18,492.69	770.53	3,082.1**
Error	35	8.62	0.25	
Total	69	93,267.77		

Chloride

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Locations	4	154,240.30	38,560.07	24,405.1**
Dates	6	23,931.08	3,988.51	2,524.4**
Loc x Date	24	54,141.09	2,255.88	1,428.4**
Error	35	55.27	1.58	
Total	69	232,367.73		

**Denotes significance at the 1% level